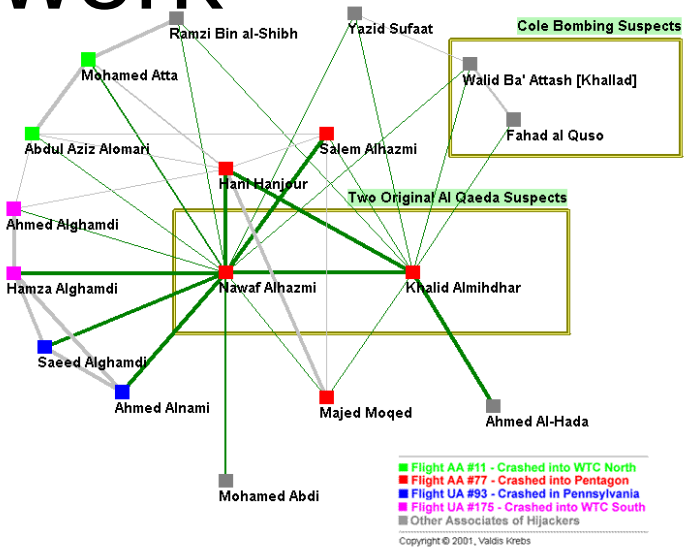
Social Network Interdiction: Reducing the Capabilities of a Terrorist Network



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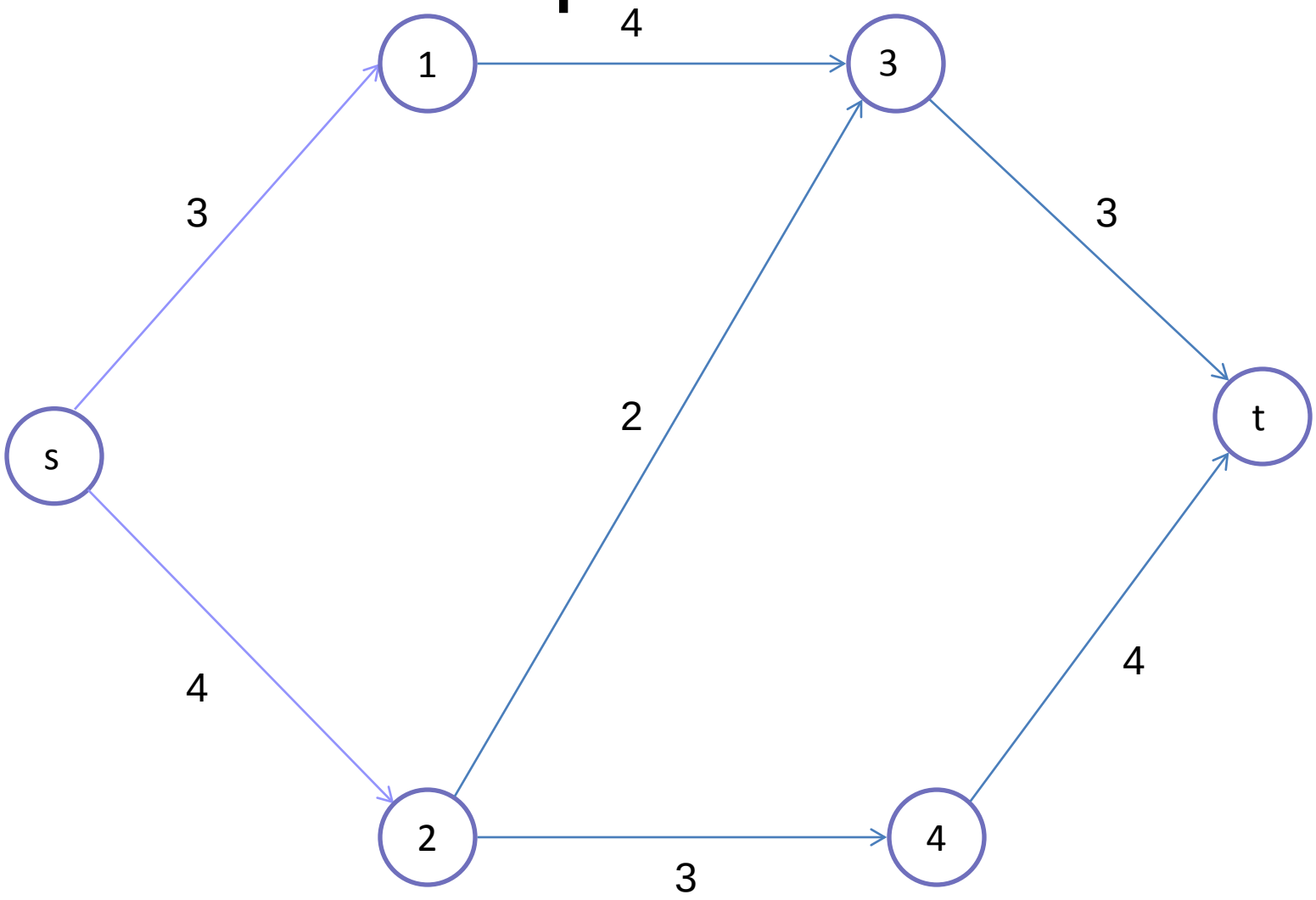
Introduction

- Who: 1/C Midshipman Honors Applied Mathematics Major at the United States Naval Academy. After graduation I will be in the U.S. Marine Corps.
- What: This project is my Senior Honors' project.
- Why: The events of 9/11 had a profound effect on me.

Sample Network



Maximum Flow Model

$$\max_{x \in A} \quad x_{ts}$$

$$\text{subject to:} \quad \sum_{(i,j) \in FS(i)} x_{ij} - \sum_{(i,j) \in RS(i)} x_{ji} = \begin{cases} x_{ts} & \text{for } i = s \\ 0 & \text{for all } i \in N \setminus \{s,t\} \\ -x_{ts} & \text{for } i = t \end{cases}$$

$$0 \le x_{ij} \le u_{ij} \qquad \forall (i,j) \in A$$

Where the *x*'s represent the flow along any arc in a network and the *u's* represent the upper bound of the flow on an arc. The arc *x(t,s)* is an artificial arc that represents the maximum flow through the network

Node Interdiction

- Terrorists want to maximize the flow of information from the planners to the people conducting the terrorist act.
- I want to minimize the flow of information.
- Arc interdiction is challenging due to current communications technology.
- Node interdiction (terrorist capture) is our solution.

Node Interdiction Model Minimize the Maximum Flow

$$\min_{w \in N} \quad \max_{x \in A} \quad x_{ts}$$

subject to:

$$\sum_{(i,j) \in FS(i)} x_{ij} - \sum_{(i,j) \in RS(i)} x_{ji} = \begin{cases} x_{ts} & \text{for } i = s \\ 0 & \text{for all } i \in N \setminus \{s,t\} \\ -x_{ts} & \text{for } i = t \end{cases}$$

$$0 \le x_{ij} \le u_{ij}(1 - w_i) \qquad \forall (i,j) \in A, \forall i \in N$$

$$0 \le x_{ji} \le u_{ji}(1 - w_i) \qquad \forall (i,j) \in A, \forall i \in N$$

$$\sum_{i \in N} r_i w_i \le R$$

$$x_{ij} \ge 0 \qquad \forall (i,j) \in A$$

$$w_i \in \{0,1\} \qquad \forall i \in N$$

Inner Dual of Node Interdiction Model

$$\min_{w \in N} \quad \min_{\theta,\pi,\gamma} \quad \sum_{(i,j)\in A} \mu_{ij}\left(1-w_i\right)\gamma_{ij} + \sum_{(i,j)\in A} \mu_{ij}\left(1-w_j\right)\gamma_{ji}$$

subject to:

$$\theta_i - \theta_j + \pi_{ij} + \gamma_{ij} + \gamma_{ji} \geq 0$$

$$\theta_t - \theta_s = 1$$

$$\sum_{i\in N} r_i w_i \leq R$$

$$\pi_{ij} \geq 0 \qquad \forall (i,j) \in A$$

$$\gamma_{ij} \geq 0 \qquad \forall (i,j) \in A$$

$$w_i \in \{0,1\} \qquad \forall i \in N$$

The dual of the inner problem causes the objective function to become non-linear.

Linearization of the objective function for the Node Interdiction Model

$$\min_{w \in N} \quad \min_{\theta,\pi,\gamma} \quad \sum_{(i,j)\in A} \mu_{ij}\beta_{ij} + \sum_{(i,j)\in A} \mu_{ij}\beta_{ij}$$

subject to:

$$\theta_i - \theta_j + \pi_{ij} + \gamma_{ij} + \gamma_{ji} \geq 0 \quad \forall (i,j) \in A, \forall i \in N$$

$$\theta_t - \theta_s = 1$$

$$\beta_{ij} - \gamma_{ij} + w_i \geq 0 \quad \forall (i,j) \in A, \forall i \in N$$

$$\beta_{ji} - \gamma_{ji} + w_j \geq 0 \quad \forall (i,j) \in A, \forall i \in N$$

$$\sum_{i \in N} r_i w_i \leq R$$

$$\pi_{ij} \geq 0 \quad \forall (i,j) \in A$$

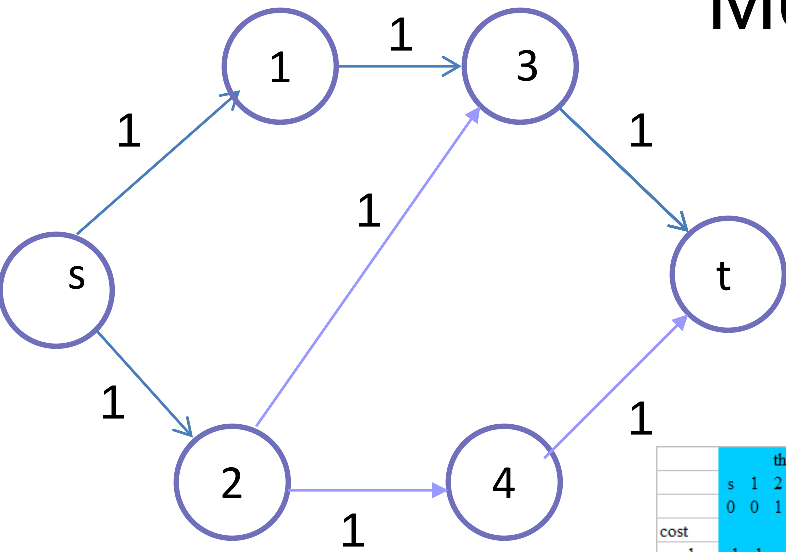
$$\gamma_{ij} \geq 0 \quad \forall (i,j) \in A$$

$$w_i \in \{0,1\} \quad \forall (i,j) \in A$$

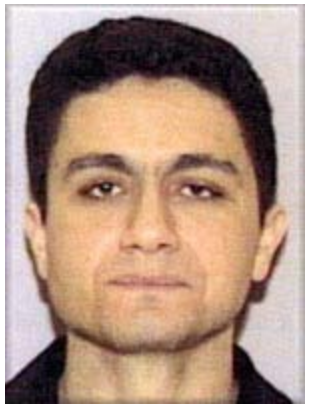
$$\beta_{ij} \in \{0,1\} \quad \forall (i,j) \in A$$

Technique described by Wood (1993) for Arc interdiction

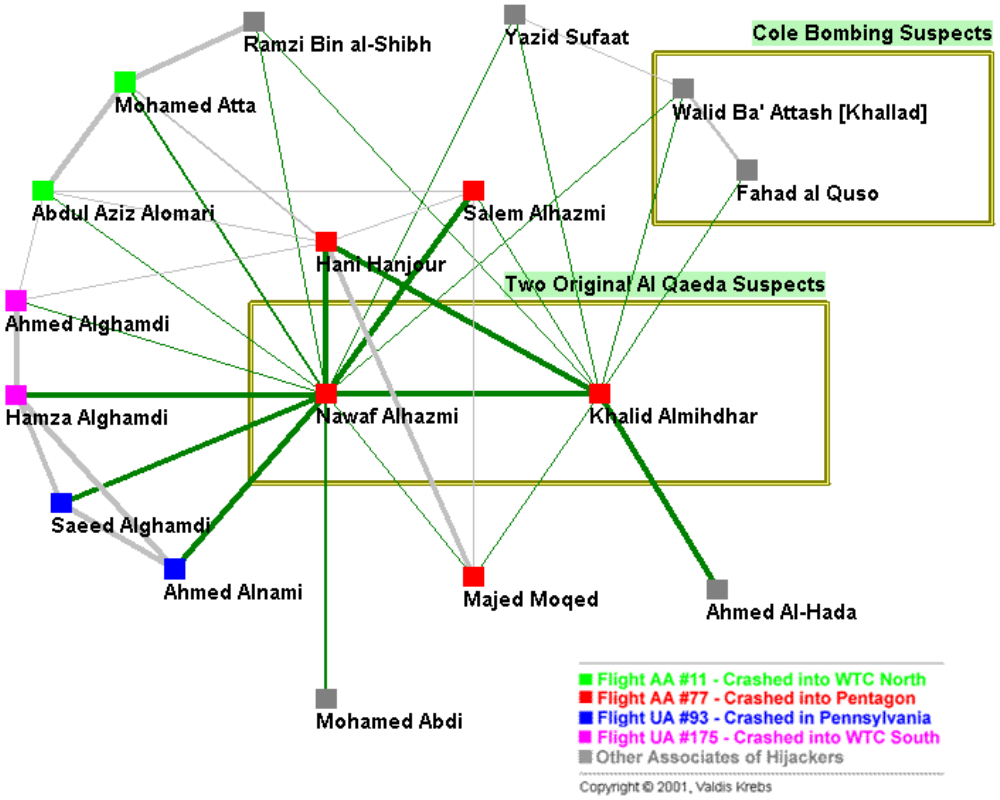
6 Node Model Network and Final Model executed in Excel



	theta						gamma																beta																interdict w								
	s	1	2	3	4	t	s1	s2	13	23	24	3t	4t	ts	1s	2s	31	32	42	t3	t4	st	s1	s2	13	23	24	3t	4t	ts	1s	2s	31	32	42	t3	t4	st	s	1	2	3	4	t			
	0	0	1	0	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	obj function		
cost																							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1		
s1	1	-1					1								1																														0	>=	0
s2	1		-1					1								1																													0	>=	0
13		1		-1					1								1																												0	>=	0
23			1	-1						1								1																											1	>=	0
24			1		-1						1								1																										0	>=	0
3t				1		-1						1								1																									0	>=	0
4t					1	-1							1								1																								0	>=	0
ts	-1					1																																							1	=	1
bs1							-1																1																1						0	>=	0
bs2								-1																1															1						0	>=	0
b13									-1																1															1					0	>=	0
b23										-1																1															1				0	>=	0
b24											-1																1														1				0	>=	0
b3t												-1																1														1			0	>=	0
b4t													-1																1														1		0	>=	0
bts														-1																1														1	0	>=	0
b1s															-1																1									1					0	>=	0
b2s																-1																1									1				0	>=	0
b31																	-1																1									1			1	>=	0
b32																		-1																1								1			1	>=	0
b42																			-1																1								1		0	>=	0
bt3																				-1																1								1	0	>=	0
bt4																					-1																1							1	0	>=	0
interdict																																							15	10	8	5	2	99	5	<=	6

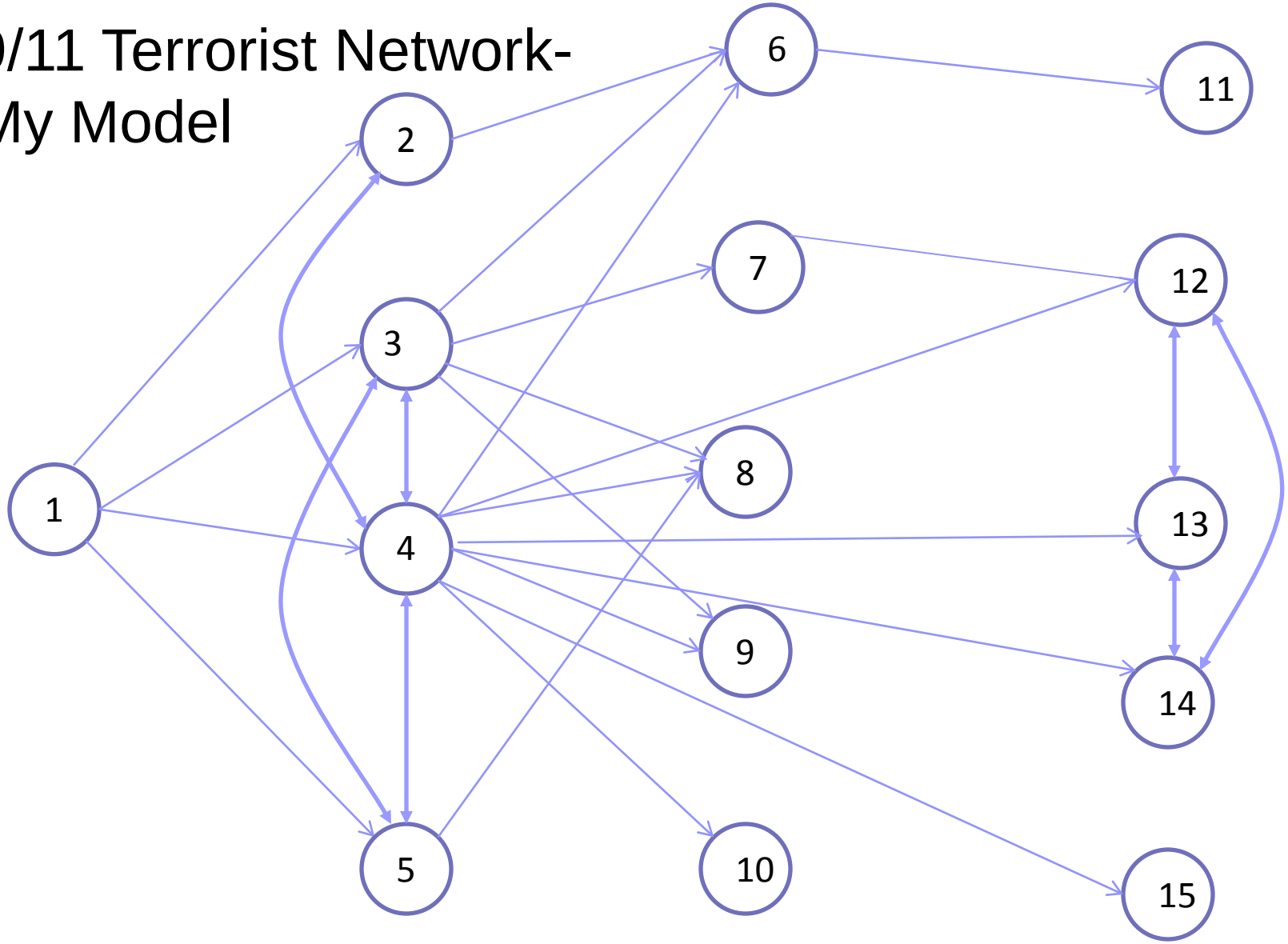


Krebs' Model



Krebs' 9/11 Network Depiction- 1 degree from the 9/11 original suspects

9/11 Terrorist Network- My Model



Results and recommendations

- For a given level of resources and the knowledge of the cost to search/capture a terrorist the model identifies which terrorist(s) should be pursued.
- Follow-on: Examine a model to determine the minimum cost to eliminate the terrorist network activity.

Extra Slides

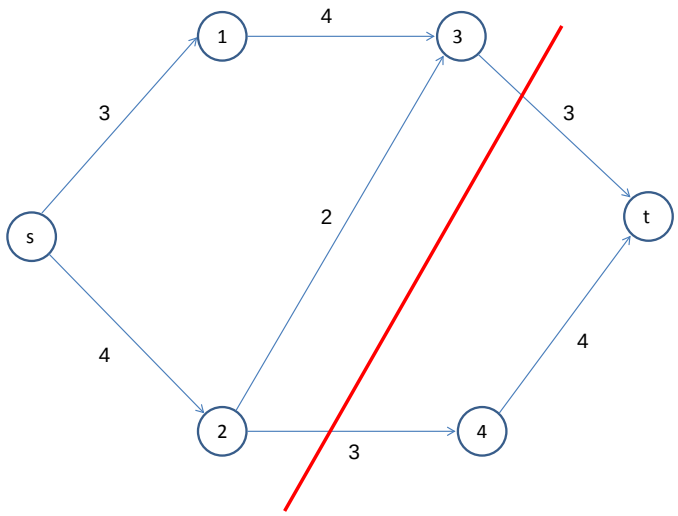
Results of Model

	R									
Terrorist	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
1	0	0	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	1	0	0	0	0	1	1	1	0
9	0	0	1	1	0	0	1	1	1	0
10	0	0	0	1	0	0	0	1	1	0
11	1	1	1	0	0	1	1	0	1	0
12	0	0	1	0	0	0	1	1	1	0
13	0	0	0	1	0	0	1	1	1	0
14	0	0	0	0	0	0	1	1	1	0
15	0	0	0	0	0	0	1	1	1	0
cost	500	2000	3000	4000	5000	5500	7000	8000	8500	10000

Minimum Cut Model

$$\min_{\theta,\pi} \quad 3\pi_{s1} + 4\pi_{s2} + 4\pi_{13} + 2\pi_{23} + 3\pi_{24} + 3\pi_{3t} + 4\pi_{4t}$$

$$\theta_s - \theta_1 + \pi_{s1} \geq 0$$
$$\theta_s - \theta_2 + \pi_{s2} \geq 0$$
$$\theta_1 - \theta_3 + \pi_{13} \geq 0$$
$$\theta_2 - \theta_3 + \pi_{23} \geq 0$$
$$\theta_2 - \theta_4 + \pi_{24} \geq 0$$
$$\theta_3 - \theta_t + \pi_{3t} \geq 0$$
$$\theta_4 - \theta_t + \pi_{4t} \geq 0$$
$$\theta_t - \theta_s = 1$$
$$\pi_{ij} \geq 0 \,\forall (i, j) \in A$$
θ_i is unrestricted in sign



Nodes of the Network

- where 1. Mohamed Atta
- 2. Ramzi Bin al-Shibh
- 3. Hani Hanjour
- 4. Nawaf Alhazmi
- 5. Abdul Aziz Alomari
- 6. Khalid Almihdhar
- 7. Ahmed Alghamdi
- 8. Salem Alhazmi
- 9. Majed Moqed
- 10. Yazid Sufaat
- 11. Ahmed Al-Hada
- 12. Hamza Alghamdi
- 13. Saeed Alghamdi
- 14. Ahmed Alnami
- 15. Mohamed Abdi